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Basic Plasma Processes in Solar-Terrestrial Activities
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# Basic Plasma Processes in Solar-Terrestrial Activities

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Within the known universe, more than 99% of all observable matter is plasma, a state often highly dynamic and far from thermal, as well as mechanical, equilibrium. In particular, for our own solar-terrestrial system, various plasma active phenomena frequently occur such as solar flares, coronal plasma heating, solar wind acceleration, and coronal mass ejections in the solar atmosphere; interplanetary magnetic clouds and collisionless shock waves in interplanetary space; and geomagnetic storms and substorms (also called Earth's aurora) in Earth's magnetosphere and ionosphere. Such phenomena are not only the most important events that are changing the space environment around our anthrosphere, but also provide natural laboratories for us to study in detail basic plasma processes encountered in astrophysics.

Since the space age began, enormous effort has been dedicated to *in situ* explorations and remote sensing observations of plasma active phenomena associated with our solar-terrestrial system. With technical improvements in observational equipment and measuring instruments on board satellites, the analysis of experimental data of these active phenomena and the relevant numerical simulations have attracted much attention from many researchers enabling remarkable progress than ever before. Meanwhile, we are having to face more and more theoretical challenges in understanding basic plasma physics processes underlying all such phenomena, such as (1) microphysical mechanisms for energy conversion in magnetic reconnections; (2) acceleration, propagation, and transport processes of energetic particle beams in collisionless magnetized plasmas; (3) microphysical mechanisms for the formation and dissipation of collisionless shock waves and other discontinuities; (4) emission mechanisms for solar radio bursts and relevant magneto-plasma diagnostic messages; (5) formation and maintenance mechanisms for various fine magneto-plasma structures (i.e. solar coronal loops, discrete auroral arcs, zonal flows, vortices, filaments); and (6) microphysical pictures of energization and thermalization of plasma particles, as well as their associated linear and nonlinear instabilities, resonant and non-resonant wave-particle interactions, and dissipative and non-dissipative turbulent wave dynamics.

Contemporary scientific studies rest on three foundation stones: theory, observation, and simulation. Of these, theory attracts the least attention. During the week of June 20–24, 2011, about 40 participants from the fields of solar physics, space physics and plasma physics met at Luoyang Normal College, Luoyang, China, to discuss some key and basic plasma physics processes in solar-terrestrial active phenomena at a mini-workshop on "Basic Plasma Processes in Solar-Terrestrial Activities", organized by Purple Mountain Observatory of Chinese Academy of Sciences, China. One of the motivating considerations for holding this workshop was to offer an opportunity for exchanges among members from different research communities working in solar physics, space physics, and plasma physics and to stimulate through a combination of longer review reports and shorter focused talks an interdisciplinary dialogue among the members working on theoretical models, data analyses, and numerical simulations.

At this workshop, there were seven invited keynote reports and more than 30 contributory talks presented in three sessions: (1) basic plasma processes in magnetic reconnection; (2) shocks and turbulent waves in the solar wind; and (3) Kinetic Alfvén waves and wave-particle interactions in space plasmas. The papers collected in this special issue of *Chinese Science Bulletin* cover four different aspects of basic plasma physics processes: (1) solar activity; (2) solar wind; (3) earth's magnetosphere; and (4) magnetic reconnection in the solar-terrestrial system. These derive from presentations given at this workshop.

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## Solar activity

The first four papers of this special issue are devoted to solar activity. The first paper, "On theories of solar type III radio bursts" (by Wu, 10.1007/s11434-012-5061-y), deals with a key topic in solar physics, in which the author discusses some essential issues and a few serious difficulties of existing theories of type III solar radio bursts that are based on the plasma hypothesis. The author also proposes probable alternative considerations that are based on electron cyclotron maser emissions. The next paper, "Solar activity studies: From a magnetohydrodynamics description to a plasma perspective" (by Wang, 10.1007/s11434-012-5089-z), reviews solar activity studies from the plasma perspective. The author starts from solar observations and their MHD descriptions, and then tries to gain some insight into what plasma problems we are facing and should be getting a better understanding. The third paper by Chen et al. (10.1007/s11434-011-4829-9) discusses an interesting question: "Where do flare ribbons stop?" Based on data analysis of flare events, the authors come to the conclusion that flare ribbons finally stop at the intersection of separatrices with the solar surface. Once verified, this can be used to predict the final size and even the lifetime of solar flares. The fourth paper of this section, "Power conversion factor in solar flares" (by Ning, 10.1007/s11434-012-5058-6), investigates transfer rates from kinetic energy of nonthermal electrons to thermal energy of flaring plasmas based on RHESSI observations and concludes that about 11.7%–34.6% of the nonthermal energy is efficiently transformed into thermal energy during the lifetime of flares.

## Solar wind

Four papers in this special issue are concerned with basic plasma physics processes in the solar wind. The paper, "An interpretation of density holes observed by Cluster and Double Star in solar wind" (by Qureshi et al., 10.1007/s11434-011-4913-1), shows that density depletions (or holes) in the solar wind that accompany bipolar electric field solitary structures frequently observed with Cluster and Double Star, can develop from linear ion acoustic waves or ion cyclotron waves in space plasmas under certain conditions. In the paper, "What geometrical factors determine the *in situ* solar wind speed?" (by Li et al., 10.1007/s11434-011-4965-2), extensive numerical examples that the authors have used to investigate the effect of curvature of magnetic field lines on local solar wind speeds are described. Their results show that the correlation between the terminal wind speed and field line curvature is valid for multi-species solar wind models as well as for rather general base boundary conditions and heating functions commonly adopted in the literature. The paper "The evidence for the evolution of interplanetary small flux ropes: Boundary layers" (by Feng et al., 10.1007/s11434-011-4960-7) examines WIND data obtained in 1996 and has identified 21 small-scale interplanetary magnetic flux ropes (IMFRs) and their boundary layer structures, which have durations varying from several minutes to half an hour. The authors find that magnetic reconnection exhausts can occur inside the boundary layers, which might be the cause for the reduction in the section-scale of the flux rope structures. This indicates that these small-scale IMFRs probably evolve from large-scale magnetic clouds, which are believed to be interplanetary propagating manifestations of coronal mass ejections originating directly from within the solar corona, because of magnetic reconnection exhausts when propagating in the planetary space. The final paper of this section, "Multi-scale pressure-balanced structures in the solar wind observed by WIND" (by Yao et al., 10.1007/s11434-011-4966-1), confirms the existence of multi-scale pressure-balanced structures (from 1000 s to 10 s) in the solar wind, based on an analysis of the anti-correlation between plasma thermal pressure and magnetic pressure measured by WIND.

## Earth magnetosphere

Six papers in this special issue discuss plasma physics processes in the magnetosphere. Since the 1990's series of great progress in experimental studies based on both space and laboratory plasma measurements, kinetic Alfvén waves (KAWs) have become an increasingly interesting topic under extensive discussions with communities working in auroral electron acceleration to coronal plasma heating; such waves are believed to play an important role in accelerating, heating, and transporting plasma particles in the ionosphere and magnetosphere as well as in the solar corona and wind. In this section, the first three papers, "Simulation of mode conversion at the magnetopause" (by Lin et al., 10.1007/s11434-012-5056-8), "Observations of kinetic Alfvén waves by THEMIS near a substorm onset" (by Duan et al., 10.1007/s11434-012-4973-x), and "Nonlinear dispersive scale Alfvén waves in magnetosphere-ionosphere coupling: Physical processes and simulation results" (by Zhao and Lu, 10.1007/s11434-011-4905-1), all report advancement in KAW research. Lin et al. report their recent results in two- and three-dimensional hybrid simulations that were performed for mode conversion from fast mode compressional waves to KAWs at the inhomogeneous magnetopause boundary. For cases in which the incident fast wave propagates in the $(x,z)$-plane, with the magnetopause normal along the $x$-axis and the background magnetic field pointing along the $z$-axis, the 2-D

($x$-$z$) simulation shows that the primary KAWs with large wave number $k_x$, satisfying $k_x\rho_i$~1 with ion gyroradius $\rho_i$, are generated near the Alfvén resonance surface. In 3-D simulations, after the initial mode conversion to primary KAWs, a subsequent generation of KAW modes with finite $k_y$ is observed that is due to nonlinear parametric decay of the primary KAWs, accompanied by a simultaneous excitation of zonal flow modes with similar large $k_y$. Since the nonlinear cascade to $k_y$ can lead to massive transport at the magnetopause, simulations indicate that this provides an effective transport mechanism at plasma boundaries in space as well as in the laboratory. In the second paper the authors present their new observation on the near-Earth magnetotail plasma sheet from the THEMIS multiple probes. In the vicinity of substorm onset, KAWs were seen to be excited in the high $\beta$ ($\beta \equiv 2\mu_0 nT/B^2$ , the ratio of plasma thermal to magnetic pressure) plasma sheet within the near-Earth magnetotail. In particular, the authors find that KAWs accelerate charged particles along magnetic field lines via the parallel electric fields of the waves, implying that KAWs play an important role in the formation of the substorm current wedge as well as in the substorm trigger process. The third paper reviews the recent progress in magnetospheric KAWs. The authors show that the field-aligned currents generated by KAWs can transport energy into the auroral ionosphere, where it is dissipated by Joule heating and leads to changes in the ionospheric Pedersen conductivity. In consequence, as a feedback, the conducting ionosphere can also strongly affect magnetospheric currents.

The fourth paper of this section, "Euler potentials' discontinuity in the presence of field line-aligned currents" (by Huang and Wu, 10.1007/s11434-012-5043-0), presents an interesting result about Euler potentials ($\alpha$, $\beta$), which are related to magnetic vector potential $\boldsymbol{A}$ by the relation $\boldsymbol{A} = \alpha\nabla\beta$, satisfying the gauge condition $\boldsymbol{A}\cdot\boldsymbol{B}$=0. The Euler potentials have been widely employed as magnetic field coordinates in both space plasma and fusion plasma studies. The authors show that in the presence of field line-aligned currents, the gauge condition is no longer valid and that the mapping of the Euler potentials ($\alpha$, $\beta$) along field lines does not properly construct Euler potential coordinates due to discontinuities. The fifth paper, "Dependence of magnetic field just inside the magnetopause on subsolar standoff distance: Global MHD results" (by Wang et al., 10.1007/s11434-011-4961-6), reports their numerical results using a global MHD model on the ratio of the compressed magnetic field just inside the subsolar magnetopause to the purely dipolar magnetic field. Results are consistent with *in situ* measurements by THEMIS. The final paper, "Long-term trends in *foF2* over Moscow ionosonde station: Its estimate and origins" (by Fang et al., 10.1007/s11434-012-5046-x), introduces a new approach to analyze the ionospheric *foF2* long-term trends analysis using IRI-2007 model from MOSCOW ionosonde observations. Their results show that the geomagnetic activity can play an important and crucial role in the ionospheric *foF2* long-term trends.

## Magnetic reconnection

Magnetic reconnection is a fundamental plasma physics process, in which energy stored in a magnetic field is converted, often explosively, into thermal and/or nonthermal kinetic energy of particles of the plasma. It is widely believed that magnetic reconnection is triggering sources for various eruptive phenomena occurring in the solar-terrestrial system, such as magnetospheric storms/substorms, solar flares, and coronal mass ejections. The final four papers of this special issue are dedicated to the discussions of this "hot" topic. The first paper, "Recent progresses in theoretical studies and satellite observations for collisionless magnetic reconnection" (by Wang et al., 10.1007/s11434-012-5045-y), reviews the development of collisionless magnetic reconnection studies and major achievements in recent years, and also briefly discusses open questions remaining to be answered in studies of collisionless magnetic reconnection. In the second paper, "Nonlinear dependence of anomalous resistivity on the reconnecting electric field in the Earth's magnetotail" (by Wu and Zhang, 10.1007/s11434-011-4902-4), based on *in situ* magnetotail measurements and particle-in-cell (PIC) simulations, the authors investigate the relationship between the anomalous resistivity and the induced electric field and show that the anomalous resistivity, resulting from the ion-acoustic/Buneman instability for a small/large reconnecting electric field, leads to favorable conditions for fast reconnection to take place in the magnetotail. The third paper of this section, "Energetic electrons associated with magnetic reconnection in the sheath of interplanetary coronal mass ejection" (by Huang et al., 10.1007/s11434-012-4974-9), reports *in situ* measurements of flux enhancement for energetic electrons with energies up to 400 keV that is associated with asymmetric reconnections occurring in the sheaths of interplanetary coronal mass ejections. The estimated reconnection rate, 0.04–0.08, is consistent with the fast reconnection theory. In the final paper, "Low-frequency waves in magnetic reconnection" (by Chai et al., 10.1007/s11434-011-4910-4), the authors investigate numerically the characteristics of low-frequency waves in magnetic reconnection and show that the low-frequency turbulence is dominated by Alfvénic ion-cyclotron waves with frequencies below $0.3\omega_{ci}$ ($\omega_{ci}$ the ion gyrofrequency) in the out-flow region but in the in-flow region the waves have higher frequencies, sometimes above $0.4\omega_{ci}$.

The papers collected in this special issue deal with a few significant aspects of plasma active phenomena in the solar-terrestrial system, with a special focus on basic plasma-physics processes underlying these active phenomena. There still are some brilliant papers presented in this meeting that have not been collected in this special issue. For example, the report by

Professor G. K. Park, entitled "Entropy generation across Earth's collisionless bow shock", presented the first direct measurements of entropy density changes across Earth's bow shock and showed that the results support the model of the Vlasov analysis (Phys Rev Lett, 2012, 108: 061102). The keynote report by Professor L. Chen, entitled "Gyrokinetic theory of parametric decays of kinetic Alfven waves", reexamined the fundamental parametric decay processes of KAWs by employing the nonlinear gyrokinetic equations. He concluded that, for the short-wavelength KAWs with $k_\perp \rho_i > \sqrt{\omega/\omega_{ci}}$ , the decay processes are significantly enhanced over and qualitatively different from the ideal magnetohydrodynamic results. Other keynote report by Professor Z. Y. Pu, entitled "Magnetic reconnection in magnetospheric plasmas", not only reviewed progresses in both theory and observation of magnetic reconnection researches in magnetospheric physics, but also presented their up to date results of observational analyses on probable magnetic reconnection events in the magnetosphere. Certainly, many other important topics have been left out. We hope, however, that this special issue will stimulate continuing efforts in understanding more extensively and comprehensively these basic plasma physics processes.

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